

**Public Health Goal for
PENTACHLOROPHENOL
in Drinking Water**

Prepared by

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December 1997

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We thank the U.S. EPA's Office of Water, Office of Pollution Prevention and Toxic Substances, and National Center for Environmental Assessment for their peer review of the PHG documents, and the comments received from all interested parties.

PREFACE

Drinking Water Public Health Goal of the Office of Environmental Health Hazard Assessment

This Public Health Goal (PHG) technical support document provides information on health effects from contaminants in drinking water. The PHG describes concentrations of contaminants at which adverse health effects would not be expected to occur, even over a lifetime of exposure. PHGs are developed for chemical contaminants based on the best available toxicological data in the scientific literature. These documents and the analyses contained in them provide estimates of the levels of contaminants in drinking water that would pose no significant health risk to individuals consuming the water on a daily basis over a lifetime.

The California Safe Drinking Water Act of 1996 (amended Health and Safety Code, Section 116365) requires the Office of Environmental Health Hazard Assessment (OEHHA) to adopt PHGs for contaminants in drinking water based exclusively on public health considerations. The Act requires OEHHA to adopt PHGs that meet the following criteria:

1. PHGs for acutely toxic substances shall be set at levels at which scientific evidence indicates that no known or anticipated adverse effects on health will occur, plus an adequate margin-of-safety.
2. PHGs for carcinogens or other substances which can cause chronic disease shall be based solely on health effects without regard to cost impacts and shall be set at levels which OEHHA has determined do not pose any significant risk to health.
3. To the extent the information is available, OEHHA shall consider possible synergistic effects resulting from exposure to two or more contaminants.
4. OEHHA shall consider the existence of groups in the population that are more susceptible to adverse effects of the contaminants than a normal healthy adult.
5. OEHHA shall consider the contaminant exposure and body burden levels that alter physiological function or structure in a manner that may significantly increase the risk of illness.
6. In cases of scientific ambiguity, OEHHA shall use criteria most protective of public health and shall incorporate uncertainty factors of noncarcinogenic substances for which scientific research indicates a safe dose-response threshold.
7. In cases where scientific evidence demonstrates that a safe dose-response threshold for a contaminant exists, then the PHG should be set at that threshold.
8. The PHG may be set at zero if necessary to satisfy the requirements listed above.
9. OEHHA shall consider exposure to contaminants in media other than drinking water, including food and air and the resulting body burden.
10. PHGs adopted by OEHHA shall be reviewed periodically and revised as necessary based on the availability of new scientific data.

PHGs adopted by OEHHA are for use by the California Department of Health Services (DHS) in establishing primary drinking water standards (State Maximum Contaminant Levels, or MCLs). Whereas PHGs are to be based solely on scientific and public health considerations without regard to economic cost considerations, drinking water standards adopted by DHS are to consider economic factors and technical feasibility. For this reason PHGs are only one part of the information used by DHS for establishing drinking water standards. PHGs established by

OEHHA exert no regulatory burden and represent only non-mandatory goals. By federal law, MCLs established by DHS must be at least as stringent as the federal MCL if one exists.

PHG documents are developed for technical assistance to DHS, but may also benefit federal, state and local public health officials. While the PHGs are calculated for single chemicals only, they may, if the information is available, address hazards associated with the interactions of contaminants in mixtures. Further, PHGs are derived for drinking water only and are not to be utilized as target levels for the contamination of environmental waters where additional concerns of bioaccumulation in fish and shellfish may pertain. Often environmental water contaminant criteria are more stringent than drinking water PHGs, to account for human exposures to a single chemical in multiple environmental media and from bioconcentration by plants and animals in the food chain.

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SUMMARY

A Public Health Goal (PHG) of 0.4 ppb is developed for pentachlorophenol (PCP) in drinking water. The U.S. Environmental Protection Agency's (U.S. EPA's) Maximum Contaminant Level (MCL) and Maximum Contaminant Level Goal (MCLG) for PCP are 1 ppb and zero, respectively. PCP is a chlorinated aromatic organic chemical with low volatility and is used as a wide-spectrum biocide; its main use is as a wood preservative. Because it is so widely used and persistent in the environment, it can be detected at many locations in soil or other environmental samples but it is not often found in California drinking water. PCP has both noncarcinogenic and carcinogenic health effects. PCP is a proven carcinogen in rodent studies and there is some epidemiological evidence that PCP is carcinogenic in humans. U.S. EPA places PCP in class B2, probable human carcinogen, based on inadequate data in humans and adequate data in laboratory animals. The International Agency for Research on Cancer (IARC) places PCP in group 2B, possibly carcinogenic to humans, based on inadequate evidence in humans and sufficient evidence in experimental animals. However, the human data are inadequate for calculation of a PHG. Therefore, the PHG calculation is based on carcinogenic effects (adenoma and carcinoma) in male mice in a 1989 National Toxicology Program (NTP) bioassay. Using these data, the Office of Environmental Health Hazard Assessment (OEHHA) calculated a $q1^*$ of $8.34 \times 10^{-2} \text{ (mg/kg-day)}^{-1}$ and a human equivalent oral cancer slope factor (CSF) of $8.11 \times 10^{-2} \text{ (mg/kg-day)}^{-1}$. Based on the CSF, and assuming a 70 kg body weight, a *de minimis* theoretical excess individual lifetime cancer risk level of 1×10^{-6} and 2 L/day water over a 70-year lifetime for an adult consumption, OEHHA calculates a PHG of 0.0004 mg/L (0.4 ppb) for PCP in drinking water.

INTRODUCTION

PCP is a broad spectrum pesticide which has found use in the past in a wide variety of applications including as a disinfectant and as a wood preservative. Today it is restricted to use as a wood preservative in specified outdoor applications such as utility poles. It rarely occurs as a water contaminant. The toxicology of PCP has been thoroughly studied, and has been reviewed in a toxicological profile by the Agency for Toxic Substances and Disease Registry (ATSDR, 1989), and more recently by IARC (1991). A toxicological review and health risk assessment was prepared for the California Department of Health Services (DHS) by the Risk Assessment Group of the Department of Environmental Toxicology of the University of California, Davis (Hsieh, 1990). All of the studies considered together make it clear that PCP is a highly toxic material that can have serious health consequences both as a carcinogen and in terms of noncarcinogenic health effects. Exposure to PCP may occur by inhalation, ingestion or dermal absorption.

CHEMICAL PROFILE

CAS Registry Number: 87-86-5

Synonyms: chlorophen; PCP; penchloropol; penta; pentachlorofenol; pentachlorofenolo; pentachlorophenol; 2,3,4,5,6-pentachlorophenol

Trade names: Acutox; Chem-Penta; Chem-Tol; Cryptogilol; Dowicide 7; Dowicide EC-7; Dow Pentachlorophenol DP-2 Antimicrobial; Durotox; EP 30; Fungifen; Fungol; Glazed Penta; Grundier Arbezol; Lauxtol; Lauxtol A; Liroprem; Moosuran; Pentacon; Penta-Kil; Pentasol;

Penwar; Peratox; Permicide; Permagard; Permasan; Permatox; Prilttox; Permite; Santophen; Santophen 20; Sinituho; Term-i-Trol; Thompson's Wood Fix; Weedone; Witophen P.

Pure PCP exists as colorless crystals, with little odor at room temperature. Impure PCP is dark gray to brown in color. There are two forms of PCP, pentachlorophenol, and the sodium salt of pentachlorophenol. The sodium salt dissolves easily in water whereas pentachlorophenol does not. Commercial grade pentachlorophenol contains polychlorinated phenols, polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans as contaminants. This will be designated throughout this report as tech-PCP.

PCP is manufactured in the U.S. by chlorination of phenol at 100° to 180°C with catalysts such as AlCl_3 , FeCl_3 , activated carbon and quinoline. Hydrogen chloride (HCl) and chlorine gases from the primary reactor are further treated with phenol to form pure HCl gas and a mixture of chlorinated phenols. Crude PCP is purified by distillation under reduced pressure in the presence of 0.05% to 2% (by weight) amine or alkanolamine (Freiter, 1979).

PCP is used as a fungicide and insecticide, mainly for wood preservation. U.S. consumption of PCP for 1986 was reported to be 28 million pounds (Chemical Marketing Reporter, 1987). It is currently permitted only for outdoor use as a wood preservative for specified applications such as utility poles. It must be applied by trained and certified applicators (U.S. EPA, 1997).

ENVIRONMENTAL OCCURRENCE

PCP may be found in air, soil or water. Each of these media may be a source of human exposure to PCP.

Air

Little information is available on the fate of PCP in the atmosphere. In urban areas, PCP has been found in air at concentrations of 5.7 to 7.8 ng/m³ (IARC, 1979). PCP is released directly into the atmosphere via volatilization from treated wood products, at an estimated rate of 760,000 pounds per year (Scow *et al.*, 1980).

Soil

Adsorption of PCP in soils is dependent on organic content of the soil, and on pH, being strongest in acidic soils and decreasing in neutral and basic soils. PCP in shallow surface waters can be degraded by light. PCP in soil is degraded by microorganisms. Anaerobic conditions are generally unfavorable for biodegradation (Boyle *et al.*, 1980; Wong and Crosby, 1981).

Water

PCP enters water as an effluent from manufacturing plants, by leaching from treated wood and by runoff after application as a herbicide, molluscicide or fungicide. Photolysis and biodegradation are believed to be the important transformation processes for PCP in aquatic systems. The rate of photolysis of PCP in aqueous solution is rapid, with total degradation within five to seven days. Photolysis in the environment would only occur close to the surface. Genetically adapted microorganisms transformed PCP in water much more rapidly under aerobic conditions than under anaerobic conditions (Liu *et al.*, 1981).

PCP was measured in water samples from five sites along the California aqueduct between 1974 and 1976 (Cirelli, 1978). Values ranging from 0.01 to 16 mg/L were reported for these water samples. PCP was not found in the 1986 survey of water contaminants in large water systems in California mandated by AB 1803.

METABOLISM AND PHARMACOKINETICS

Pharmacokinetics includes absorption, distribution, metabolism and excretion. An understanding of the pharmacokinetics of PCP is needed to extrapolate from animal exposures in experiments to human environmental exposures. The effective dose of a chemical is its concentration in the target tissues. These target tissue concentrations can only be predicted by modeling the pharmacokinetics of the compound based on available pharmacokinetic data from animal and human studies.

Absorption

PCP is readily absorbed following the inhalation, dermal and ingestion routes of exposure in animals and in humans. Human male volunteers who received oral doses of 0.1 mg/kg sodium pentachlorophenol reached the maximum plasma concentration (0.24 mg/mL) within four hours. The plasma half-life of PCP was calculated as 1.3 ± 0.4 hours (Braun *et al.*, 1979).

Distribution

PCP is distributed to all tissues of the body. The levels in liver and kidney are particularly high, whereas those in fat, brain and muscle are relatively low (Larsen *et al.*, 1972; Braun *et al.*, 1977).

Metabolism and Excretion

In rats, metabolism of PCP involves conjugation, reductive dechlorination, hydrolytic dechlorination and oxidation (Renner and Hopfer, 1990). Rat metabolism occurs via oxidation to tetrachlorohydroquinone and to a lesser extent to trichlorohydroquinone, as well as by glucuronidation (Jacobson and Yllner, 1971; Ahlborg and Thunberg, 1980). In male volunteers, PCP given orally was eliminated as both the parent compound and the glucuronide. No other metabolites were observed in these experiments (Braun and Sauerhoff, 1976; Braun *et al.*, 1979; Uhl *et al.*, 1986). About 86% of the total dose was excreted in the urine, and 4% in the feces in the eight days following PCP administration (Braun *et al.*, 1979). The remaining 10% is either excreted later or remains in the organism.

The half-lives for urinary elimination of PCP and PCP glucuronide were approximately 33 hours and 13 hours, respectively. The slow urinary excretion rate was attributed to enterohepatic recirculation (Braun *et al.*, 1979). Tetrahydroquinone (TCHQ) was measured in urine of humans exposed to PCP in an occupational setting (Ahlborg *et al.*, 1974).

The metabolism of PCP may be affected by diet and by the amount of body fat. The amount of body fat would influence the amount of PCP and fat-soluble metabolites in the liver where they are subjected to the action of liver enzymes (Umezaki *et al.*, 1993). The pharmacokinetics of the impurities in PCP are more complex. Some of them may affect the metabolism of PCP by stimulating mixed function oxidases (Goldstein *et al.*, 1977).

TOXICOLOGY

Toxicological data from human exposure is not adequate for a full assessment of the potential health effects of PCP on humans. Therefore, data from animals and other model systems must be used to estimate the potential health effects to humans. Many of the toxic effects of PCP are due to its effect as an uncoupler of oxidative phosphorylation. PCP acts as a protonophore and allows passage of protons across energy-generating membranes without coupling to the energy-generating system (Barstad *et al.*, 1993).

Toxicological Effects in Animals

Acute Toxicity

The acute oral LD₅₀ is 130 mg/kg for mice and 184 mg/kg for rats (Demidenko, 1969). The dermal LD₅₀ for rats is 96 mg/kg. The inhalation LD₅₀ is 335 mg/m³ for rats and 225 mg/m³ for mice.

Deichmann *et al.* (1942) examined the effects of acute exposure to sodium salts of PCP in rats, guinea pigs, rabbits and dogs. The effects observed included elevated blood pressure, hyperglycemia, hyperperistalsis, glycosuria and motor weakness leading to asphyxial convulsive movements and immediate, profound *rigor mortis*. Borzelleca *et al.* (1984) exposed CD-1 ICR mice to single oral doses of PCP, resulting in central nervous system (CNS) depression, increased respiration, motor weakness, tremors and convulsions.

Subchronic Toxicity

A number of investigators (Knudsen *et al.*, 1974; Goldstein *et al.*, 1977; Kimbrough and Linder, 1978; Schwetz *et al.*, 1978; NTP, 1989) consistently observed decreased body weight in rats and mice exposed subchronically or chronically to oral doses of technical grade PCP (tech-PCP) or purified PCP. Schwetz *et al.* (1978) exposed Sprague-Dawley rats to 1.0, 3.0, 10 or 30 mg/kg of tech-PCP in their feed continuously for 22 to 24 months and observed decreased weight gain only at the highest dose. Holstein cattle were exposed to PCP at doses of 0.2 to 2.0 mg/kg in their feed for 43 days (Hughes *et al.*, 1985). The cattle exhibited hyperthermia, diarrhea, rapid respiration and anorexia, along with decreased weight gain. Hyperthermia appears to be a consequence of the decoupling of oxidative phosphorylation. Decreased weight gain would be expected in animals that experienced these toxic effects.

Chronic Toxicity

Exposure of laboratory animals to PCP appears to affect primarily the liver, kidneys, central nervous system and skin. These effects are summarized in Table 1.

Liver

Acute and chronic exposure of mice and rats to PCP has caused adverse liver effects (NTP, 1989; Nishimura *et al.*, 1982; Fleischer *et al.*, 1980; Kimbrough and Linder, 1978; Goldstein *et al.*, 1977; Knudsen *et al.*, 1974; Johnson *et al.*, 1973). Wistar rats exhibited increased liver weights

after a single oral administration of 30, 60, 120 or 150 mg/kg PCP (Nishimura *et al.*, 1982). This effect was not observed at 10 mg/kg.

Female Sherman rats orally exposed to 1, 6 or 30 mg/kg tech-PCP for eight months exhibited increased liver to body weight ratios (Kimbrough and Linder, 1978). When exposed to purified PCP for the same duration, a dose of 30 mg/kg was required to produce this effect (Goldstein *et al.*, 1977), indicating that the impurities in PCP probably contribute significantly to this observed liver toxicity.

B6C3F1 mice administered 1,250 mg/kg tech-PCP, Dowicide EC-7 (91% purity) or purified PCP in the feed for 30 days showed increased liver weight and increased liver to body weight ratio (NTP, 1989). These two grades of PCP contain polychlorinated phenols, polychlorinated dibenzop-dioxins, and polychlorinated dibenzofurans as contaminants. However, in a six month experiment in which male and female mice were administered tech-PCP and purified PCP, increased absolute and relative liver weights were observed in both male and female mice at lower doses with tech-PCP and at higher doses with purified PCP. See Table 2 for details.

Histological changes, including centrilobular cytomegaly, vacuolization of the cytoplasm, focal hepatocellular degeneration and necrosis and accumulation of yellow to brown pigment in macrophages and Kupffer cells, were observed in the livers of rats and mice exposed chronically or subchronically to tech-PCP or purified PCP (Johnson *et al.*, 1973; Knudsen *et al.*, 1974; Kimbrough and Linder, 1978; Fleischer *et al.*, 1980; NTP, 1989). Hepatocellular degeneration and necrosis were seen in Sprague-Dawley rats exposed for 90 days to 30 mg/kg tech-PCP in their feed; however, when the exposure was to purified PCP for the same period, no histopathological changes were reported (Johnson *et al.*, 1973).

Enlarged liver was also observed in Holstein cows given 0.2 mg/kg PCP in their feed for 84 days and 2 mg/kg for the following 60 days (Kinzell *et al.*, 1981).

Table 1. No-Observed-Adverse-Effect-Levels (NOAELs) and Lowest-Observed-Adverse-Effect-Levels (LOAELs) for PCP Tested for Noncarcinogenic Endpoints in Animals

Species/ strain	Route	Sex	N*	Dose Regimen	NOAEL	LOAEL	Endpoint	Reference
Acute								
Studies: rat, Wistar	gavage	male	4-18 (6)	single dose	10 mg/kg		increased hepatic glycogen	Nishimura <i>et al.</i> (1982)
Subchronic								
Studies: rat, Sprague-Dawley	feed	NR	NR	90 day	3 mg/kg-day		hepatocellular degeneration and necrosis	Johnson <i>et al.</i> (1973)
rat, Sprague-Dawley	gavage	female	20 to 40	days 6-15 of gestation		5 mg/kg-day	fetal resorptions	Schwetz <i>et al.</i> (1974)
rat, Wistar	intra-peritoneal	male	NR	daily for 15 days		30 mg/kg-day	altered hepatic ultrastructure	Fleischer <i>et al.</i> (1980)
rat, Wistar	feed	male, female	10 (4)	12 weeks	(m) 1.21 mg/kg-day, (f) 1.64 mg/kg-day		anemia, centrilobular vacuolization in liver	Knudsen <i>et al.</i> (1974)
mice, C5751/6J	feed	male	NR	10-12 weeks		5 mg/kg-day	tumor growth susceptibility	Kerkvliet <i>et al.</i> (1982)
pigs	oral capsule	NR	6 (4)	daily, for 30 days	5 mg/kg-day		leukopenia	Greichus <i>et al.</i> (1979)
Chronic								
Studies: rat, Sherman	feed	female	6 (4)	daily for 8 months	6 mg/kg-day		increased hepatic enzymes and porphyrin	Goldstein <i>et al.</i> (1977)
rat, Sprague-Dawley	feed	male, female	10M, 20F (3) (reproductive study)	62 days before mating, during mating, during gestation & lactation to day 21 post weaning	3 mg/kg-day		embryo-lethality	Schwetz <i>et al.</i> (1978)
rat, Sprague-Dawley	feed	male, female	25 (5) (chronic toxicity study)	22 months (males), 24 months (females)	10 mg/kg-day (males), 3 mg/kg-day (females)		Increased liver enzyme activity, increased liver and kidney pigmentation	Schwetz <i>et al.</i> (1978)

* Number of animals per sex per group. The number of dose groups is given in parentheses.
NR = not reported.

Male Wistar rats, administered 2.43 to 9.36 mg/kg PCP and female rats administered 3.14 or 13.12 mg/kg PCP for 12 weeks in their feed, exhibited centrilobular vacuolization of the livers (Knudsen *et al.*, 1974). Centrilobular cytomegaly and cytoplasmic eosinophilic inclusions in the livers of Wistar rats fed 1 to 30 mg/kg tech-PCP were more pronounced than in Wistar rats administered 30 mg/kg purified PCP (Kimbrough and Linder, 1978). In a study by NTP, B6C3F1 mice were fed 23.0 to 327.3 mg/kg tech-PCP, Dowicide EC-7, DP-2 or purified PCP for 30 days in their feed for two years, resulting in karyomegaly, nuclear atypia and bile duct hyperplasia with

periportal fibrosis (NTP, 1989). The lesions were more diffuse and more severe in mice exposed to tech-PCP than in mice exposed to other grades of PCP. Six-week-old chickens exposed to 10 to 100 mg/kg PCP in feed for eight weeks showed proliferative changes in bile duct and fatty degeneration of the liver (Stedman *et al.*, 1980).

Investigators observed ultrastructural changes in livers of rats fed PCP, including proliferation of smooth endoplasmic reticulum (SER), the presence of lipid vacuoles and small pleomorphic mitochondria (Fleischer *et al.*, 1980; Kimbrough and Linder, 1978). Fleischer *et al.* (1980) observed enlarged sinusoids, multinucleated hepatocytes and increased heterochromatin to euchromatin ratio in rats exposed to 30 mg/kg PCP for 15 days.

Table 2. Doses that Were Effective in Producing Changes in Absolute and Relative Liver Weights in Male and Female B6C3F1 Mice (NTP, 1989).

Test Animal	Grade of PCP	Effective Doses (mg/kg)
male mice	tech-PCP	28.5, 85.4, 256.3
female mice	tech-PCP	36.4, 109.1, 327.3
male mice	purified PCP	85.4, 213.6
female mice	purified PCP	109.1, 272.7

Rats administered 1 to 1,250 mg of PCP in their diet developed histochemical changes and elevated total liver porphyrin and cytochrome P₄₅₀, serum glutamic pyruvic transaminase (SGPT), glutamic pyruvic transaminase (GPT), serum glutamic oxaloacetic transaminase (SGOT), aryl hydrocarbon hydroxylase (AHH) and glucuronyl transferase (NTP, 1989; Kimbrough and Linder, 1978; Goldstein *et al.*, 1977). Wistar rats given single doses of 120 or 150 mg/kg of PCP had increased hepatic glycogen and lactate (Nishimura *et al.*, 1982). Rats administered 1, 6 or 30 mg/kg tech-PCP or purified PCP in their feed for eight months had increased cytochrome P₄₅₀, glucuronyl transferase and AHH (Goldstein *et al.*, 1977). The effects were much higher when tech-PCP was used as compared to purified PCP.

Mice administered 4.8 to 1,250 mg/kg tech-PCP or purified PCP had increased mean cholesterol, serum alkaline phosphatase (SAP) and SGPT (NTP, 1989). The greatest changes in SGPT were seen in the higher dose groups of tech-PCP. Rats administered 45 to 90 mg/kg tech-PCP in their feed for six months exhibited increased porphyrin excretion in their urine (Wainstok de Calmanovici and San Martin de Viale, 1980). When purified PCP was used there was no increase in porphyrin excretion. The authors interpreted this difference as evidence that the impurities in tech-PCP were mainly responsible for the toxic effects.

Kidneys

The predominant gross change associated with acute or chronic exposure of laboratory animals to PCP is increased kidney weight (Hughes *et al.*, 1985; Kinzell *et al.*, 1981; Stedman *et al.*, 1980; Kimbrough and Linder, 1978; Johnson *et al.*, 1973; Blevins, 1965). Swine exposed to lumber

treated with 5% tech-PCP exhibited hemorrhages, subcapsular fluid and a spongy texture of the kidney (Blevins, 1965; Schipper, 1961).

Mice administered one dose of 148 to 1,250 mg/kg PCP in their diet had darkening of the urine (NTP, 1989). Rats exhibited accumulation of pigment in the kidneys and increased specific gravity of the urine after receiving 10 to 30 mg/kg PCP in their diet for two years (Schwetz, 1978).

Rabbits that were administered 1.3, 7.5, 27.5 or 70 mg/kg PCP subcutaneously, or 15 mg/kg intraperitoneally, exhibited hemorrhage, congestion, lymphocytic infiltration of the cortex and albuminous or fatty degeneration of the kidneys (McGavach *et al.*, 1941). A cow which accidentally ingested 5% PCP in kerosene had extensive necrosis of the convoluted tubules (Spenser, 1957).

Holstein bulls administered 1 to 10 mg/kg PCP in their diet for 43 days had functional impairment of the kidneys (Hughes *et al.*, 1985). Cattle administered 0.2 mg/kg PCP in their feed for 75 to 84 days then 2 mg/kg for 50 to 60 days exhibited interstitial nephritis and thickened Bowman's capsule (Kinzell *et al.*, 1981).

Chickens administered 100 to 1,000 mg/kg of PCP in their feed exhibited increased kidney weight (increasing from a mean of 12.4 for the controls, up to 15.9 and 18.3 grams for the two top doses), however there was no effect when they received 1 to 10 mg/kg (Stedman, *et al.*, 1980). The kidney was the organ with the highest accumulation of PCP in these chickens.

Respiratory System

Sprague-Dawley rats exposed to a single dose of 31 or 449 mg/kg of tech-PCP evinced rapid respiration after 25 minutes (St. Omer and Gadusek, 1987). Similar effects have been reported in rabbits, mice and pigs (McGavack *et al.*, 1941). Piglets in contact with wooden crates that had been treated with PCP developed necrosis of the external nares (Schipper, 1961).

Cattle had increased lung weight resulting from exposure to 15 to 20 mg/kg PCP in feed for 160 days (McConnell *et al.*, 1980). Mice administered 28.5 to 327.3 mg/kg PCP for six months were observed to have histopathological lesions, including metaplasia of the nasal mucosa (NTP, 1989). Rabbits administered daily subcutaneous or intraperitoneal injections of PCP suffered partial collapse of their lungs (McGavack *et al.*, 1941). Pigs exposed to 5% PCP on wood pens for 1 to 12 days developed congestion and emphysema (Blevins, 1965; Schipper, 1961). A cow that accidentally ingested 5% PCP in kerosene developed signs of internal tissue bleeding in the tracheal mucosa and ulcerations of the mucosa of the pharynx and larynx (Spencer, 1957).

Central Nervous System

Mice injected intraperitoneally with one dose of 65 to 252 mg/kg purified PCP exhibited depression of the central nervous system (Borzelleca, *et al.*, 1985). Rabbits acutely exposed by subcutaneous or intraperitoneal injections of 50 to 700 mg/kg of PCP exhibited no gross changes in the brain or spinal cord. Likewise, dogs injected subcutaneously with 125 to 175 mg/kg of PCP exhibited no changes in central nervous system (CNS) function (McGavack *et al.*, 1941).

Exposure of rabbits to 13.7, 27.5 or 70 mg/kg of PCP by subcutaneous injection or to 15 mg/kg of PCP by intraperitoneal injection daily for 60 days resulted in listlessness, frequent defecation and

slight motor weakness. Convulsive seizures resulting in death as well as histopathological changes were observed in rabbits exposed to 450 mg/kg (McGavack *et al.*, 1941).

Skin

Rabbits exposed to one cutaneous application of 60 to 600 mg/kg PCP exhibited edema, inflammation and desquamation as well as tanning of the skin (McGavack *et al.*, 1941). Rabbits administered 60 to 600 mg/kg of PCP for four to seven days exhibited hyperkeratinization of the epidermis and hypertrophy of the hair follicles (McGavack *et al.*, 1941).

Deichmann *et al.* (1942) reported no wrinkling of the skin or hair loss in rabbits administered 40 mg/kg dermally each day for 100 days. Cattle administered 20 mg/kg tech-PCP in their feed for 160 days exhibited dilation and mild to moderate hyperkeratosis of the ductal lining of the meibomian glands in the eyelids (McConnell *et al.*, 1980).

Immune System

Splenic antibody production and serum antibody titers were suppressed in mice administered 5 to 50 mg/kg of tech-PCP in feed for 10 to 12 weeks. No response was seen with purified PCP. However, mice exposed to purified PCP exhibited enhanced development of splenic tumors resulting from challenge with Moloney sarcoma virus-induced tumor cells (Kerkvliet *et al.*, 1985, 1987).

Rats administered to 100 mg/kg tech-PCP in their feed for 14 days exhibited suppressed complement activity. Mice administered the same dose exhibited suppressed IgM antibody response to sheep red blood cells. Mice exposed to purified PCP exhibited neither of these responses (Holsapple *et al.*, 1987).

Mice administered tech-PCP by gavage for 30 days or six months exhibited increased thymus and spleen weight (NTP, 1989). Decreased lymphocyte populations were observed in mice administered tech-PCP in the diet for 30 days. TECH-PCP but not purified PCP caused decreases in plaque-forming cell response in mice (NTP, 1989).

Cardiovascular and Hematologic Systems

Rabbits administered 50 to 700 mg/kg PCP subcutaneously, intraperitoneally or orally evinced a marked drop in blood pressure followed by a sharp rise and then another drop (McGavack *et al.*, 1941). Dogs exhibited cardiac arrest when administered 125 to 175 mg/kg PCP (McGavack *et al.*, 1941).

Tech-PCP but not purified PCP caused reduced red blood cell count and hemoglobin as well as reduced cell volume in Sprague-Dawley rats administered 30 mg/kg-day in the diet for 90 days (Johnson *et al.*, 1973). Rabbits exhibited leukopenia, with relative lymphocytosis and decreased hemoglobin when injected subcutaneously with 27.5 mg/kg of PCP per day for 60 days (McGavack *et al.*, 1941). Likewise, pigs experienced transient leukopenia when administered 5, 10 or 15 mg/kg PCP in the diet for 30 days (Hillam and Greichus, 1983).

Male mice exposed to doses ranging from 4.8 to 1,250 mg/kg PCP and female mice exposed to doses ranging from 6.3 to 1,250 mg/kg PCP in their feed for 30 days exhibited lymphopenia, leukopenia, monocytosis and thrombocytosis (NTP, 1989).

Rabbits administered 13.7 to 70 mg/kg PCP for 160 days exhibited dilation of the right side of the heart and usually contraction of the left side (McGavack *et al.*, 1941). Sprague-Dawley rats administered 3, 10 or 30 mg/kg-day of tech-PCP in the diet for 90 days exhibited increased serum alkaline phosphatase (SAP), as did mice receiving PCP for 30 days. The mice also showed increased cholesterol levels (NTP, 1989). In a study by Johnson *et al.* (1973), rats administered tech-PCP for 30 days exhibited decreased serum albumin.

Reproductive and Developmental Toxicity

Both purified PCP and tech-PCP have been studied in rodents and swine by a number of investigators. Decreased fetal body weight on days 9 and 10 of gestation as well as malformations such as dwarfism, exencephaly, macrophthalmia and absence of tail were observed in Charles River rats administered one dose of 60 mg/kg of purified PCP on day 8, 9, 10, 11 or 12 of gestation (Larsen *et al.*, 1975). Larsen *et al.* (1975) studied the teratogenic effects and placental transfer of PCP in CD rats, by administered single oral doses of 60 mg/kg on days 8, 9, 10, 11, 12 or 13 of gestation. This dose was chosen as 75% of the LD₅₀ (Monsanto, 1948). The PCP was administered to the rats by gavage in olive oil. Fetuses were removed and examined on day 20 of gestation. Fetuses were examined for viability, cutaneous reflex, weight and gross external malformations and half were checked for skeletal abnormalities.

Fetal weights were lower than the controls when the PCP was administered on day 9 or 10. One dwarf was found among the fetuses from day eight administration. The day nine treatment produced three malformations in three different rat fetuses. These malformations were exencephaly, macrophthalmia and absence of tail. There were also a number of resorption sites. There were no malformations found in the control groups.

¹⁴C-labeled PCP was used to study placental transfer. Less than 0.2% of the labeled PCP entered the fetus. The investigators concluded that transfer of PCP across the placenta was "negligible." This leads to the possibility that malformations observed in the fetuses are an indirect effect, or are caused by extremely low concentrations of PCP in fetal tissue.

Schwetz *et al.* investigated both purified PCP and tech-PCP in Sprague-Dawley rats. The only effects reported due to purified PCP exposure was decreased fetal weight and decreased crown-to-rump length resulting from a dose of 30 mg/kg purified PCP. A wider variety of toxic effects was reported for tech-PCP, including significant decrease in maternal body weight, increased fetal resorptions, altered sex ratios and decreased fetal body weight (Schwetz *et al.*, 1974).

Increased conception rate, increased number of stillbirths and decreased body weight were observed in Sprague-Dawley rats exposed continuously for 10 weeks to 0.5, 5 and 50 mg/kg (Exon and Koller, 1982). Male and female Sprague-Dawley rats administered 60, 200 or 600 ppm purified PCP in their feed (4, 13 or 43 mg/kg) for 181 days prior to mating and during gestation showed a dose-related decrease in fetal body weight, embryoletality (43 mg/kg), increased fetal resorptions, decreased crown-to-rump length and increased fetal skeletal variations (13 mg/kg) (Welsh *et al.*, 1987).

Golden Syrian hamsters exhibited fetal death and resorption when exposed orally to 1.25 to 20 mg/kg of PCP during days 5 to 10 of gestation (Hinkle, 1973). An increased number of stillbirths and post-partum deaths occurred to swine exposed to PCP-treated pens for an unspecified number of days prior to giving birth (Schipper, 1961). Reduction in fetal body weight (at 75 mg/kg) and decreased maternal body weight gain (at 40 mg/kg) as well as increased fetal resorption (at 40 mg/kg) were observed in rats exposed to tech-PCP or purified PCP by intraperitoneal injection (Courtney *et al.*, 1976; Chou and Cook, 1979).

In summary, both tech-PCP and purified PCP appear to be embryotoxic and teratogenic in rodents. However, tech-PCP appears to be more potent than purified PCP indicating that the impurities probably contribute significantly to the developmental toxicity of this material.

Genetic Toxicity

For the most part, PCP has not manifested significant genotoxic activity in those *in vitro* or *in vivo* systems in which it has been tested (NTP, 1980; Hattula and Knuutinene, 1985; Borzelleca *et al.*, 1984; Legator *et al.*, 1982; Lawlor and Haworth, 1979; Simmon *et al.*, 1977; Mattern, 1975; Vogel and Chandler, 1974). Technical grade PCP was not mutagenic in *Salmonella typhimurium* strains TA98, TA100, TA1535 and TA1537 at doses up to 30 mg/plate with or without S9 enzyme activation (NTP, 1989).

PCP exhibited weak activity in sister-chromatid exchange (SCE) and chromosome aberration assays in Chinese hamster ovary (CHO) cells. In the chromosome aberration assay, PCP was weakly positive only with S9 activation. Statistically significant increases in abnormal metaphases were observed at 80 or 100 mg/mL PCP. A weakly positive SCE response was observed in the absence of S9 at 3.0 to 30 mg/mL PCP. However, no SCE induction was observed in the presence of Aroclor-induced rat liver S9 at the same dosages (NTP, 1989). Purified PCP (99% pure) at 400 mg/L was observed to induce forward mutations and intragenic recombinations, but not intergenic recombinations, in *Saccharomyces cerevisiae* (Fahrig *et al.*, 1978).

Tech-PCP caused DNA damage in prokaryotes and eukaryotes (Waters *et al.*, 1982). Tech-PCP was positive in the *Bacillus subtilis* strain 45 recA differential toxicity assay. Tech-PCP was also positive in the *S. cerevisiae* D3 assay (Waters *et al.*, 1982).

Fahrig *et al.* (1978) tested purified PCP for mutagenicity in the mammalian spot test to detect somatic cell mutations *in vivo*. They bred female C57BL/6JHan mice (homozygous recessive at one coat color locus; otherwise wild type) to males of the "T-stock" (homozygous recessive at five coat color loci), yielding embryos that were heterozygous at four different recessive coat-color loci. The dams were administered a single intraperitoneal injection of either 50 or 100 mg/kg purified PCP on day 10 of gestation. The pups were examined for color spots twice weekly from two to five weeks *post partum*. Nine of the 473 pups exhibited color spots on their fur, four of which were judged to be definite mutations. A single gray spot and a single light brown spot were observed in the 50 mg/kg dose group. One light gray and one gray spot were observed in the 100 mg/kg dose group. Only one of the 967 control pups had a color spot that definitely was a result of mutation. The authors concluded that this experiment indicated that purified PCP was unequivocally but weakly mutagenic (Fahrig *et al.*, 1978).

Tetrachlorohydroquinone (TCHQ) the major metabolite of PCP is more toxic to Chinese hamster ovary (CHO) cells than PCP itself, and causes DNA single-strand breaks and alkali-labile sites at

concentrations of 2 to 10 mg/mL as demonstrated by the alkaline elution technique (Ehrlich, 1990). TCHQ induced thioguanine resistant mutants in V79 Chinese hamster cells, indicating that TCHQ may be at least partly responsible for the genotoxic activity of PCP (Jansson and Jansson, 1991).

Carcinogenicity

In March 1989, NTP published the results of a two-year bioassay of PCP on male and female B6C3F1 mice. The data from this experiment are summarized in Table 3. Mice were exposed to two different grades of PCP: tech-PCP (90.4% pure) and Dowicide EC-7 (91% pure). These two grades of PCP contain polychlorinated phenols, polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans as contaminants. The test material was mixed with the animals' feed at concentrations of 0, 100, 200 and 600 ppm. There was no 600 ppm exposure group for tech-PCP, because this material was too toxic at this level. Based on food consumption and the weights of the mice, the doses were calculated in mg/kg-day for each exposure group. The 100 and 200 ppm exposure levels corresponded to doses of 17 to 18 and 34 to 37 mg/kg-day, respectively. The highest exposure level, 600 ppm, corresponded to 114 mg/kg-day in female mice and to 116 mg/kg-day in male mice.

Increases in non-neoplastic and neoplastic lesions were produced by both grades of PCP in both sexes of mouse. Tech-PCP produced higher tumor incidences than EC-7, presumably because of greater contamination with carcinogens such as dioxins and furans. Hepatocellular adenomas and carcinomas were increased in a dose-related manner in male mice exposed to either tech-PCP or EC-7; the increase in incidence was less marked in female mice.

Pheochromocytomas in male mice were significantly increased over controls for both tech-PCP and EC-7. Pheochromocytomas were also increased in female mice exposed to EC-7 at the highest dose but not in those exposed to tech-PCP. Hyperplasia of the adrenal medulla occurred with increased incidence in male or female mice exposed to either tech-PCP or EC-7.

High-dose female mice that received either tech-PCP or EC-7 had significantly greater incidences of hemangiosarcomas in the spleen and liver. Compound-related non-neoplastic lesions were also observed in the livers, spleens and noses of male and female mice exposed to either tech-PCP or EC-7.

Table 3. Carcinogenicity Bioassay of Pentachlorophenol in B6C3F1 Mice (NTP, 1989)

Technical Grade (tech-PCP)				q1* human (mg/kg-day) ⁻¹	CSF human (mg/kg-day) ⁻¹	upper-bound cancer risk level (ppb) based on q1*	upper-bound cancer risk level (ppb) based on CSF
<u>Male Mice</u>	0 mg/kg -day	18 mg/kg -day	35 mg/kg- day				
pheochromocytoma	0/31	10/45	23/45	1.55E-01	1.47E-01	0.23	0.24
hepatocellular adenoma	5/32	20/47	33/48	2.38E-01	2.25E-01	0.15	0.15
hepatocellular carcinoma	2/32	10/47	12/48	8.13E-02	7.72E-02	0.43	0.45
hepatocellular adenoma and carcinoma	7/32	26/47	37/48	3.13E-01	2.97E-01	0.11	0.11
<u>Female Mice</u>	0 mg/kg -day	17 mg/kg -day	35 mg/kg- day				
hemangiosarcoma	0/35	3/50	6/50	4.17E-02	3.98E-02	0.84	0.88
Dowicide EC-7							
<u>Male Mice</u>	0 mg/kg -day	18 mg/kg -day	37 mg/kg- day	116 mg/kg -day			
pheochromocytoma	0/34	4/48	21/48	44/49	9.10E-02	8.54E-02	0.39
pheo & malignant pheochromocytoma	1/34	4/48	21/48	45/49	9.66E-02	7.47E-02	0.36
hepatocellular adenoma	5/35	13/48	17/46	32/49	7.65E-02	7.16E-02	0.46
hepatocellular carcinoma	1/35	7/48	7/49	8/49	1.19E-02	2.55E-02	1.86
hepatocellular adenoma & carcinoma	6/35	19/48	21/48	34/49	8.34E-02	8.11E-02	0.42
<u>Female Mice</u>	0 mg/kg -day	17 mg/kg -day	34 mg/kg- day	114 mg/kg -day			
pheochromocytoma	0/35	1/49	2/46	38/49	1.59E-02	8.70E-03	2.20
pheo & malignant pheochromocytoma	0/35	2/49	2/46	38/49	2.15E-02	1.22E-02	1.63
hepatocellular adenoma	1/34	3/50	6/49	30/48	3.63E-02	2.99E-02	0.96
hepatocellular adenoma & carcinoma	1/34	4/50	6/49	31/48	3.57E-02	3.39E-02	0.98
hemangiosarcoma	0/35	1/60	3/50	8/49	1.70E-02	1.58E-02	2.05
hemangioma & hemangiosarcoma	0/35	1/50	3/50	9/49	1.83E-02	1.73E-02	1.91

Legend: All data sets in this table passed the test for goodness of fit (i.e., had p values for the Monte Carlo test greater than 0.05). The test material was mixed with animal feed at 0, 100, 200 and 600 ppm (600 ppm dose omitted for tech-PCP because of toxicity). Dose calculated in mg/kg-day based on body weight and food consumption.

q1* = the 95% upper confidence limit on the slope of the linearized multistage dose-response curve.
CSF = the cancer slope factor as defined below in the section on the LED₁₀ model.

Table 4. National Toxicology Program 1989 Bioassay Conclusions

Test Material	Sex and Species	NTP "Level of Evidence"	Tumor Types
tech-PCP	male mice	"clear"	adrenal medullary and hepatocellular neoplasms
	female mice	"some"	hemangiosarcomas and hepatocellular neoplasms
Dowicide EC-7	male mice	"clear"	adrenal medullary and hepatocellular neoplasms
	female mice	"clear"	adrenal medullary and hepatocellular neoplasms

NTP evaluated the data from this study and concluded that there was clear evidence of carcinogenicity¹ of tech-PCP in male mice based on adrenal medullary and hepatocellular neoplasms, and some evidence of carcinogenicity² of this test material in female mice based on hemangiosarcomas and hepatocellular neoplasms. EC-7 showed clear evidence of carcinogenicity in both male and female mice based on adrenal medullary and hepatocellular neoplasms. These conclusions are summarized in Table 4.

As can be seen in Table 3, there was a high background incidence of hepatocellular neoplasms (adenomas and carcinomas) in the male B6C3F1 mice. This strain of mice frequently exhibits a high background rate of hepatocellular neoplasms, raising some doubt as to their relevance to human carcinogenicity. However, the positive trend for this data set was highly significant, based on both Monte Carlo and Chi-square tests.

Toxicological Effects in Humans

Most of the information about the health effects of PCP in humans comes from occupational settings where workers are exposed to high levels of the chemical. The workers who are exposed to these high levels are those who work in the production of PCP, or in its application in wood treatment plants, as well as those who handle treated wood and use it in fabricating cooling towers and other outdoor structures. Very little information is available on the long-term effects of low level exposures to PCP.

¹ Clear evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing a dose-related (i) increase of malignant neoplasms, (ii) increase of a combination of malignant and benign neoplasms, or (iii) marked increase of benign neoplasms if there is an indication from this or other studies of the ability of such tumors to progress to malignancy (NTP, 1989).

² Some evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing a chemically related increased incidence of neoplasms (malignant, benign, or combined) in which the strength of the response is less than that required for clear evidence (NTP, 1989).

Acute and Short-Term Toxicity

Irritation of the skin, the nasal and respiratory tracts and the eyes result from nonfatal exposures to PCP (U.S. EPA, 1985). Repeated skin exposure to sodium pentachlorophenate caused dermatitis, and occasionally an allergic response (Dow Chemical Co., 1969). Corneal damage leading to permanent impairment of vision was also observed when PCP came into contact with the eyes. Koppers Company conducted a retrospective study of its 1,670 employees who were occupationally exposed to PCP in wood preservative plants (American Wood Preservers Institute, 1977). Twenty-six cases of PCP-related health problems were reported in this study. The most frequent symptoms were conjunctivitis, allergies, dermatitis and skin burn (American Wood Preservers Institute, 1977).

Fatal exposures of humans to PCP cause profuse sweating, fatigue, intense thirst, nausea, vomiting, general weakness, anorexia, abdominal pain, hyperpyrexia, tachycardia, tachypnea, severe terminal spasms, progressive coma and death within 3 to 30 hours of the onset of these symptoms (Menon, 1958; Bergner *et al.*, 1965; Chapman and Robson, 1965; Mason *et al.*, 1965; Robson *et al.*, 1969; Wood *et al.*, 1983). In fatal cases, an intense form of *rigor mortis* is often observed.

Twenty newborn infants became ill and two died after brief exposures to PCP from nursery linens laundered in an antimicrobial neutralizer containing 22.9% sodium pentachlorophenate. Two neonates developed characteristic signs of PCP poisoning including excessive sweating, fever, tachycardia, tachypnea, hepatomegaly and metabolic acidosis (Armstrong *et al.*, 1969; Robson *et al.*, 1969).

A drinking water well contaminated with 12.5 ppm PCP caused illnesses in approximately twelve people who used water from the well for drinking and bathing. All of the exposed individuals had irritated throats, fever and increased pulse and respiratory rates and were flushed (Uede *et al.*, 1962; Chapman and Robson, 1965). Two children who were exposed were intermittently delirious and excitable, but recovered completely after a week of no exposure (Chapman and Robson, 1965). The health of the other exposed individuals improved after two or three days of no exposure (Uede *et al.*, 1962).

Fifteen members of three families were exposed to PCP in the air in their homes. The maximum air concentrations were 0.4, 0.95 and 1.2 mg/m³ (Sangster *et al.*, 1982). Symptoms reported for these exposed individuals were painful burning sensations of the skin of the face and hands, erythema, dryness and scaling of the skin, drowsiness, nausea, decreased appetite, fatigue, pain upon breathing deeply and swelling of the eyelids. These symptoms gradually disappeared after exposure ceased.

Chronic Toxicity

Occupational exposure of lumber mill workers to a wood preservative containing PCP was the subject of a two-year study (Kleinman *et al.*, 1986). Ten workers in the PCP production department of a manufacturing plant had histories of severe skin eruptions, and all but one had extensive acne more than a year after production was suspended. Eight of the workers reported neuralgia of the legs and feet. Four complained of persistent bronchitis. Also reported were palpitations of the heart, disturbances of the *libido*, bursitis of the elbow, acute upper respiratory

irritation and lacrimation (Baader and Bauer, 1951). Dermal exposure of one worker to PCP for approximately one year resulted in fatal aplastic anemia (Roberts, 1963).

Data from occupational exposure usually involves the inhalation route of exposure, and is usually long-term. The underlying mechanism which accounts for most of the clinical observations is an increase in the metabolic rate to compensate for loss of energy from uncoupling of oxidative phosphorylation (Williams, 1982).

Liver

PCP exposure causes gross, histological and biochemical alterations of the liver. Enlargement and fatty degeneration of the liver have been caused by both occupational and accidental exposures (Gorski *et al.*, 1984; Wood *et al.*, 1983). Two infants who died following PCP poisoning exhibited swollen hepatocytes with numerous small cytoplasmic vacuoles (Robson *et al.*, 1969). These infants also exhibited fatty metamorphosis of the liver.

Three male PCP factory workers, and another male who accidentally drank a wood preservative containing 5.2% PCP in a kerosene/naphtha mixture, all exhibited severe centrilobular congestion of the liver with numerous fat droplets in hepatocytes (Gray *et al.*, 1965; Mason *et al.*, 1965; Stevens and Richardson, 1979).

One hundred and twenty workers from a PCP manufacturing plant were found to have increased levels of triglycerides and decreased levels of total serum cholesterol, lactate dehydrogenase (LDH) and total bilirubin (Baxter, 1984). However, these changes were not statistically significant, and there was no discernible change in other liver enzymes such as SGPT, SGOT and GGT. These workers were exposed to 0.5 to 16.5 mg/m³ PCP for periods of three months to over 20 years.

A woman was chronically exposed to PCP in her wooden house that had been extensively treated with chlorophenol preservatives. She exhibited liver damage together with increased activity of SGPT, SGOT, GGT, LDH and glutamate dehydrogenase (GLDH) (Brandt *et al.*, 1977).

Kidneys

A six-day-old girl and a twelve-day-old boy who died within 3 and 46 hours, respectively, of the first signs of PCP intoxication, exhibited kidneys that were pale with fat vacuoles in the cytoplasm of epithelial cells of the proximal convoluted tubules (Robson *et al.*, 1969). These effects were attributed to percutaneous absorption of PCP used in laundering of the infants' diapers and linens. The laundry product contained 23% NaPCP, 4% 3,4,4-trichlorocarbanilide, 3.2% sodium salts of other chlorophenols and inert ingredients.

Other PCP poisoning cases have involved hydropic and fatty degeneration of the renal tubules, or slight congestion of the kidney (Bergner *et al.*, 1965; Wood *et al.*, 1983; Gray *et al.*, 1985; Mason *et al.*, 1965; Stevens and Richardson, 1979). Elevated blood urea nitrogen (BUN), proteinuria, ketonuria and acidosis have been characteristic of PCP poisoning cases (Chapman and Robson, 1965; Robson *et al.*, 1969; Gray *et al.*, 1985).

A four-year-old child who was poisoned (via a contaminated water supply) with an insecticide mixture containing PCP was found to have generalized aminoaciduria in addition to the usual biochemical abnormalities mentioned above (Chapman and Robson, 1965). The insecticide

mixture also contained b-naphthol and dieldrin in an oily solvent. The child had washed and bathed in the contaminated water for 13 days. Forty hours after hospitalization the concentration of PCP in the urine was 6 mg/100 mL, but no dieldrin was detected.

Evidence of reversible renal dysfunction was observed in 18 workers at a wood treatment plant (Begley *et al.*, 1977). Creatinine clearance and phosphorus resorption values were depressed prior to a 20-day vacation period but showed significant improvement during vacation, suggesting that PCP exposure transiently reduced both the glomerular filtration rate and tubular function (Begley *et al.*, 1977).

Heart

Fatalities due to PCP poisoning have sometimes been attributed to cardiac arrest (Bergner *et al.*, 1965; Stevens and Richardson, 1979; Ahlborg and Thunberg, 1980; Wood *et al.*, 1983), however, few cardiac abnormalities have been reported following nonlethal poisoning. One fatality resulting from occupational exposure was a 58-year-old man whose cardiac rhythm was irregular because of episodes of sinus arrest and nodal premature beats (Bergner *et al.*, 1965). Cardiac dilation and fatty degeneration of the heart have been commonly observed during pathological examination of industrial fatalities (Truhaut *et al.*, 1952; Menon, 1958; Bergner *et al.*, 1965; Mason *et al.*, 1965; Robson *et al.*, 1969; Wood *et al.*, 1983; Gray *et al.*, 1985). Pallor of the myocardium and cardiomegaly have also been reported (Robson *et al.*, 1969).

A 16-year-old male who had sprayed a 1% solution of NaPCP as a herbicide in an Australian pineapple plantation for three hours per day, two days per week for four weeks, developed hyperpyrexia, hyperpnea, general flaccidity and a slight neck stiffness (Gordon, 1956). This individual, who had worn no protective clothing, died 21 hours after the onset of the symptoms. A *post-mortem* examination revealed fragmentation of some muscle fibers of the heart, as well as degeneration of intravascular leukocytes.

In a similar incident, a 14-year-old male, who had prepared a 2.5% NaPCP solution and sprayed it for several hours per day for an unspecified number of weeks, died without medical attention within 18 hours of a final full-day exposure to the solution. Autopsy of this individual revealed scattered hemorrhages in the subpericardial fatty tissues (Gordon, 1956).

Hematopoietic System

A woman exposed to PCP in an insecticide she used to clean furniture, developed intravascular hemolytic anemia (Hassan *et al.*, 1985). Laboratory examination of a blood sample collected from the patient revealed decreased hemoglobin, decreased white blood cell count and up to 30% reticulocytosis. Microcytosis, spherocytosis and anisocytosis were observed in peripheral blood smears. The investigators' interpretation was that PCP causes hemolysis by blocking formation of ATP (Hassan *et al.*, 1985).

A man who handled wet lumber processed with a product containing 3% PCP and 1.5% tetrachlorophenol died from aplastic anemia. The same preparation caused aplastic anemia in three patients, and red cell aplasia in two others (Roberts, 1981; Roberts, 1983). One of the patients with red cell aplasia later developed acute leukemia (Schmid *et al.*, 1963), and another had Hodgkin's disease in the left cervical nodes (Roberts, 1983).

Five workers were discovered to have leukemia after working at an army depot where high concentrations of PCP were found in the ambient air from PCP-treated lumber (Roberts, 1983). A construction worker regularly exposed to PCP presented with severe aplastic anemia, and later developed Hodgkin's disease in the left supraclavicular nodes (Louwagie *et al.*, 1978). These findings suggest that PCP may simultaneously damage the bone marrow and initiate lymphoproliferation. Klemmer *et al.* (1980) found a significant association ($p < 0.005$, ANOVA) between PCP exposure and the occurrence of increased immature band neutrophils and basophils, along with increased alkaline phosphatase concentrations.

Enlarged spleens were reported in two cases of chronic PCP exposure: a 14-year-old female with granulocytopenia, lymphocytosis and hepatomegaly (Gorski *et al.*, 1984); and a 22-year-old man with accompanying edema of the brain and lungs (Menon, 1958). The investigator suggested that the toxic effects of PCP exposure may be increased in individuals in tropical countries who consume rice diets with little protein, and that there may be racial differences in susceptibility to PCP toxicity. Two of nine infants who were exposed to toxic amounts of PCP in a nursery exhibited splenomegaly (Robson *et al.*, 1969).

Respiratory System

The clinical effects of occupational and accidental exposure to PCP on the respiratory tract have been reported as nasal stuffiness, mucosal irritation of the upper airways, tachypnea, respiratory distress and intercostal retractions, and bilateral basal crepitations on auscultation (Chapman and Robson, 1965; Baader and Bauer, 1951; Robson *et al.*, 1969; Cooper and Macauley, 1982). *Post-mortems* of patients who died from inhalation of PCP have revealed gross congestion of the lungs and acute edema (Menon, 1958; Mason *et al.*, 1965; Stevens and Richardson, 1979; Wood *et al.*, 1983; Gray *et al.*, 1985). No other pulmonary lesions were mentioned in the available literature.

Central Nervous System

Children who were bathed in PCP-contaminated water (PCP/b-naphthol/dieldrin) exhibited nose and eye irritation, fever and intermittent delirium and rigors following periods of excitability (Chapman and Robson, 1965). Another fatal case also involved delirium and convulsions (Wood *et al.*, 1983). Acute exposure to PCP has been shown to cause depression and progressive neuromuscular weakness (Ahlborg and Thunberg, 1980).

Transient cases of sciatic neuralgia among men shoveling PCP in a manufacturing plant were described by Barnes (1953). Seven cases of polyneuritis were reported in men and women, aged 36 to 61 years, who had used insecticides containing PCP (Campbell, 1952). Peripheral neuritis was found in five of these cases, and retrobulbar neuritis was found in three. Neuralgic pain in the lower extremities was reported by workers exposed to PCP (Baader and Bauer, 1951). These workers also experienced weakness of the lower limbs, paresthesia and severe pain of the gluteal and femoral regions and along the sciatic nerve. Significantly decreased sensory nerve conduction velocities were measured in 18 workers exposed for 12 years in a PCP processing factory (Trebig *et al.*, 1981).

Pathological findings related to central nervous system effects of PCP exposure include focal neuronal degeneration as well as cerebral edema with focal swelling of the myelin sheaths in the white matter (Gordon, 1956; Bergner *et al.*, 1965; Robson *et al.*, 1969; Wood *et al.*, 1983; Gray *et al.*, 1985).

Immune System

Significant increases in immunoglobulins occurred among occupationally exposed individuals, whose plasma levels of PCP ranged from 0.2 to 2.4 mg/mL (Zober *et al.*, 1981). Workers exposed to PCP were found to have conjunctivitis, chronic sinusitis and upper respiratory infections (Klemmer *et al.*, 1980). A highly significant ($p < 0.005$) association was found between PCP exposure and an increased number of band neutrophils (immature leukocytes) after controlling for age and ethnicity (Klemmer *et al.*, 1980).

Pancreas

Two cases of PCP poisoning involved pancreatic effects. The first case, a 51-year-old man occupationally exposed to "Cuprinol Clear" wood preservative containing PCP and zinc naphthenate, initially manifested abdominal pain, anorexia, vomiting and a dark-colored urine (Cooper and Macaulay, 1982). This individual was found to have pancreatitis, together with increased levels of serum bilirubin, aspartate transaminase, alanine transferase, gamma-glutamyltranspeptidase and amylase. The authors judged that PCP was "highly likely to have been the cause of the pancreatitis."

The second case involved another 51-year-old man who accidentally drank 53 mL of wood preservative containing 5.2% PCP (2.8 g of PCP) and upon pathological examination exhibited gross congestion of the pancreas (Stevens and Richardson, 1979). The pancreas, kidneys and intestines of this individual showed greater than normal epithelial autolysis.

Skin

Many incidents of human exposure to PCP result from direct dermal contact during industrial or home use. An adult male who immersed his hands for 10 minutes in a 0.4% solution of PCP had reddening and pain in his hands that persisted for two hours. Urinary PCP levels had returned to background levels one month after the episode (Bevenue *et al.*, 1967). A man whose job involved scooping PCP into a pail had chronic diffuse urticaria and angioedema of the hands (Kentor, 1986). Two cases of *pemphigus vulgaris* (skin eruptions characterized by large vesicles, usually 2 cm or more in diameter) occurred in individuals who were exposed to PCP in a nonoccupational setting (Lambert *et al.*, 1986). Chronic urticaria was observed in a case with increased anti-skin antibodies. In each of these cases the symptoms correlated well with serum PCP levels, ranging from 15 mg/L to 143 mg/L (Lambert *et al.*, 1986).

Many studies have reported an association between commercial PCP and chloracne, which is characterized by folliculitis and comedones with secondary infection (U.S. EPA, 1980). However, the occurrence of chloracne in PCP workers may be caused by the chlorinated dioxin and dibenzofuran contaminants in PCP (Johnson *et al.*, 1973; Cole *et al.*, 1986).

Rashes and skin irritations commonly result from acute or chronic exposure to PCP (Klemmer *et al.*, 1980; Sangster *et al.*, 1982; Kleinman *et al.*, 1986). Three patients experienced burning sensations, erythema, dryness and scaling caused by exposure to PCP in the air (Sangster *et al.*, 1982).

Reproductive System

The available evidence on the effect of PCP on the human reproductive system is sketchy and inconclusive. Four of 10 workers chronically exposed to PCP complained of "disturbances of libido" (Baader and Bauer, 1951). Exposure was not quantitated in this study, but it was sufficient to cause a range of symptoms, including severe acne, eye irritation and neuralgic pain of the lower extremities.

A 25-year-old woman reported headache, dizziness and fatigue approximately one month after moving with her family into a restored house that had been treated with a 5.5% solution of PCP in white spirit followed by linseed oil (Sangster *et al.*, 1982). The concentration of PCP in the house air during the second month of exposure was 0.7 mg/m³. The woman experienced a spontaneous abortion after three months of residence in the house. No physical or biochemical abnormalities were found during clinical examination of this woman (Sangster *et al.*, 1982). There is no evidence that establishes a causal relationship between the PCP exposure and the spontaneous abortion.

Developmental Toxicity

The birth outcomes of 737 wives of employees of a chemical company in Michigan were investigated by means of an interviewer-administered questionnaire (Townsend *et al.*, 1982). The wives of employees with potential exposures to dioxins and PCP were compared to a control group of wives of employees with no such potential exposure. No significant association was found between PCP exposure and adverse reproductive outcomes (Townsend *et al.*, 1982).

Genetic Toxicity

Wyllie *et al.* (1975) observed no change in frequency of chromosomal aberrations such as breaks or gaps when they examined peripheral lymphocytes (25 per person) of six workers occupationally exposed to 263 to 1,887.9 mg/m³ for 20 to 54 years. Schmid *et al.* (1982) and Bauchinger *et al.* (1982) conducted more detailed investigations of the potential cytogenetic effect of PCP. Three hundred lymphocytes per individual, from 22 workers who were exposed to 0.1 to 0.5 mg/m³ PCP in factory air for 1 to 30 years, were examined for SCE and structural chromosome changes. There was a significant increase ($p < 0.05$, Mann-Whitney U-test) in the number of cells with structural chromosomal changes. The damage was mainly of the chromosomal type, with significantly increased numbers of dicentric and acentric chromosomes. No increase in the numbers of chromatid type aberrations, such as breaks and exchanges, or in the frequency of gaps, was found. Schmid *et al.* (1982) termed this a "weak clastogenic effect."

Carcinogenicity

U.S. EPA categorizes PCP as a probable human carcinogen (B2) based on its analysis of the available evidence (Integrated Risk Information System, 1997). U.S. EPA regards the human data to be inadequate, but the animal data to be sufficient to indicate that PCP is a probable human carcinogen. The human data were obtained from a study of 182 men who worked in the wood treatment industry in Hawaii. These men had elevated levels of PCP in their urine, but there was no increase in morbidity or mortality from cancer in this group (Gilbert *et al.*, 1990). U.S. EPA judged this study to be "uninformative."

A number of epidemiological studies and case reports have identified an association between PCP or exposures to chemicals used in wood preservative industries and manufacture and certain kinds of cancer, including soft-tissue sarcoma, malignant lymphoma, nasal and nasopharyngeal cancer, as well as liver and colon cancer.

Soft-tissue Sarcoma

A case-control study of soft-tissue sarcoma and exposure to chlorophenols (not restricted to PCP), used in Sweden as a fungicide for slime control in the production of paper pulp, and to chlorophenoxy herbicides was conducted by Hardell and Sandstrom (1979). These investigators calculated a soft tissue sarcoma relative risk ratio of 6.6 ($p < 0.001$) for workers exposed to chlorophenols. Many of these pesticides contained chlorinated dibenzodioxins and dibenzofurans as impurities. The investigators concluded that the increased risk of soft-tissue sarcoma among those using these pesticides may be attributable to these impurities rather than to the chlorophenols and chlorophenoxy compounds (Hardell and Sandstrom, 1979).

A later case-control study in Sweden, which excluded individuals with exposure to chlorophenoxy herbicides, found a soft-tissue sarcoma relative risk ratio of 3.3 for individuals exposed to chlorophenols (Eriksson *et al.*, 1981). A soft-tissue sarcoma relative risk ratio of 1.6 was calculated for individuals exposed to chlorophenols for five days or longer, 10 years prior to diagnosis (Smith *et al.*, 1984).

Malignant Lymphoma

A Swedish case-control study of 169 cases of malignant lymphoma and 338 controls was reported by Hardell *et al.* (1981). This study was conducted in a manner similar to the Swedish soft-tissue sarcoma studies cited above. Relative risk ratios were 2.2 for "low" exposure to chlorophenols, and 7.6 for "high" exposure. "Low" exposure was defined as continuous exposure to chlorophenols for not more than one week, or repeated brief exposures for not more than one month; longer exposures were classified as "high." There appeared to be no difference between Hodgkin's and non-Hodgkin's lymphoma in terms of the excess risk generated by exposure to chlorophenols.

A New Zealand case-control study of non-Hodgkin's lymphoma was reported by Pearce *et al.* (1986). This study involved 83 cases, 168 controls with other types of cancer and 228 general population controls. The relative risk ratio was calculated to be 1.2 when comparing cases to other cancer patients, and 1.4 when comparing cases with general population controls.

Two case reports of non-Hodgkin's lymphoma in the scalp among 158 male workers exposed to chemicals for five years at a PCP manufacturing plant were reported by Bishop and Jones (1981). Both individuals had also been exposed to aromatic hydrocarbons such as benzene, as well as to hexachloro- and octachloro-dibenzodioxins which occurred as contaminants, at concentrations up to 300 ppm, in the manufacturing intermediates. Cases of chloracne were also reported from this plant. The expected number of neoplasms of this type for a group of 158 men would be 0.28.

Workers in the wood and lumber industries had an increased relative risk of developing Hodgkin's disease (Green *et al.*, 1978). These investigators examined the occupational statements on death certificates in several North Carolina counties, where a significant part of the population was involved in lumbering and furniture manufacturing. A total of 167 deaths from Hodgkin's disease

occurred among white males in the study population. Two controls with other causes of death were matched to each case by sex, race, county of death, age and year of death. The relative risk for Hodgkin's disease for workers in the wood and paper industries was 1.4 (95% confidence interval: 0.8 to 2.3). Carpentry and lumbering had the highest relative risk ratio, 4.2 (95% C.I.: 1.4 to 12.5).

Nasal and Nasopharyngeal Cancer

Workers in sawmills can be exposed to chlorophenols during wood impregnation or through inhalation of dust, especially in those plants where the lumber is handled after treatment with chlorophenols (Levin *et al.*, 1976).

Forty-four cases of nasal cancer and 27 cases of nasopharyngeal cancer were studied in Sweden by Hardell *et al.* (1982), who compared the reported frequency of exposure to chlorophenols and other chemicals with that of the combined 541 referents from earlier studies (Hardell and Sandstrom, 1979; Eriksson *et al.*, 1981). Sawmillers and carpenters exposed to chlorophenols for more than one month were found to have a relative risk ratio for these types of cancer of 6.7 (95% C.I.: 2.8 to 16.2).

Hernberg *et al.* (1983) studied 167 cases of sinonasal cancer and 167 colorectal cancer cases in Denmark, Finland and Sweden. They found an association between sinonasal cancer and employment in the wood products industry. Two of the sinonasal cancer cases, and none of the colorectal cancer controls had probably been exposed to chlorophenols in addition to wood dust.

Another study, based on the Danish Cancer Registry, classified 839 sinonasal cancer cases and 2,465 controls according to wood dust and chlorophenol exposure. A relative risk ratio of 0.6 (95% C.I.: 0.3 to 1.2) was reported after adjustment for exposure to wood dust (Olsen and Moller Jensen, 1984).

Considering all of these studies it appears that exposure to wood dust is associated with nasal and nasopharyngeal cancer. It is not clear whether there is any association between chlorophenol exposure and these cancers. There may be other chemicals involved such as glues, shellacs, etc.

Liver and Colon Cancer

A study of colon cancer by Hardell (1981) found a relative risk ratio of 1.8 (95% C.I.: 0.6 to 5.3) for high exposure to chlorophenol, based on six exposed cases and 13 exposed referents (out of a total worker population of 541). Hardell *et al.* (1984) found a relative risk ratio for primary liver cancer of 2.2 (95% C.I.: 0.7 to 7.3) among individuals with high exposure to chlorophenols.

Summary of Carcinogenic Effects in Humans

IARC reviewed and considered all of the evidence on the carcinogenicity of pentachlorophenol (IARC, 1979; IARC, 1991). IARC concluded that there is inadequate evidence for the carcinogenicity of pentachlorophenol in humans, but sufficient evidence in experimental animals. IARC's overall conclusion is that pentachlorophenol is "possibly carcinogenic to humans" (Group 2B).

U.S. EPA similarly reviewed all of the evidence and concluded that there is inadequate evidence for carcinogenicity of pentachlorophenol in humans, but sufficient evidence in experimental animals. U.S. EPA classifies pentachlorophenol as a "probable human carcinogen," Class B2 (Integrated Risk Information System, 1993).

We agree with these other agencies that the epidemiological evidence is not adequate to identify PCP as a carcinogen in humans. Virtually all of the studies reported fail to distinguish between the effects of PCP and other confounding exposures such as wood dust and other chemicals used in the wood industry.

DOSE-RESPONSE ASSESSMENT

The purpose of this section is to identify those studies which may be acceptable for use in calculating a PHG. The objective is to identify studies with adequate data for a reliable evaluation of dose-response.

Drinking water limits can be based on either carcinogenic or noncarcinogenic effects. In this section, those studies are reviewed which have sufficient data on which to base a dose-response assessment, that is, those studies on which an NOAEL or LOAEL can be based for noncarcinogenic effects or those for which a cancer potency can be estimated.

Noncarcinogenic Effects

Table 1, which is modified from Hsieh (1990), gives the NOAELs and LOAELs for PCP based on experiments on noncarcinogenic effects in animals. All of these experiments were done with rodents, except for one which was with pigs.

Acute Studies

The acute toxicity of PCP in rats was studied by Nishimura *et al.* (1982). They found dose-related increases in liver weights at doses of 30 mg/kg-day or greater. They also found increased liver glycogen and lactate at doses of 120 to 150 mg/kg-day. The NOAEL from this study was 10 mg/kg, based on a liver weight increase of 20% at the highest dose.

Subchronic Studies

Johnson *et al.* (1973) studied the effects of purified PCP in Sprague-Dawley rats at doses of 0, 3, 10 or 30 mg/kg-day for 90 days. They found that liver weights increased at the 10 and 30 mg/kg-day doses. Kidney weights increased only at the 30 mg/kg-day dose. The NOAEL for this study was 3 mg/kg-day. U.S. EPA stated that the NOAEL from this study was 10 mg/kg-day, apparently not considering increased liver weight alone an adverse effect.

Knudsen *et al.* (1974) studied the effect of PCP in Wistar rats. Ten weanling rats per sex were fed 0, 25, 50 or 200 ppm PCP for 12 weeks. This PCP contained no TCDD, but it did contain 200 ppm OCDD and other impurities. PCP has direct effects on erythropoiesis in bone marrow and spleen. PCP uncouples oxidative phosphorylation in red blood cells. This leads to accelerated formation of red blood cells. Decreased hemoglobin may have been due to shortened red blood cell lifespans, leading to reduced ATP content in the cells (Knudsen *et al.*, 1974). The NOAEL from

this study was attained at the 25 ppm dose group, which (according to the authors) translates to a dose of 1.21 mg/kg-day for the male and 1.64 mg/kg-day for the female rats.

Schwetz *et al.* (1974) investigated teratogenicity of purified PCP (98% purity) in Sprague-Dawley rats at doses of 5, 15, 30 or 50 mg/kg-day, administered on days 6 to 15 of gestation. There were no signs of maternal toxicity. Delayed ossification of the skull was observed at doses of 5 to 15 mg/kg-day. Other soft tissue and skeletal anomalies were also observed at 15 mg/kg-day. At 30 mg/kg-day, 97.5% of the fetuses were resorbed. Resorptions rose to 100% at 50 mg/kg-day. The LOAEL from this study was 5 mg/kg-day.

Greichus *et al.* (1979) studied the effect of purified PCP in pigs at doses of 0, 5, 10 or 15 mg/kg-day for 30 days. Increased liver weights and decreased white blood cell counts were observed at 10 to 15 mg/kg-day. The NOAEL from this study was 5 mg/kg-day.

Fleischer *et al.* (1980) examined hepatotoxicity of PCP in male rats. Rats were given PCP intraperitoneally at 30 mg/kg-day. Relative liver weights increased by 24.4% in young rats and by 9.2% in old rats at this dose. Morphological changes were seen in hepatocytes, such as widening sinusoids, and increased heterochromatin to euchromatin ratio. Fat content of the cells was decreased. The LOAEL for this study was 3.52 mg/kg-day.

Kerkvliet *et al.* (1982) studied the effects of PCP pretreatment on chemical and viral tumor induction in mice. Chemical tumor induction was by 3-methyl cholanthrene (MCA); viral by Moloney Sarcoma Virus (MSV). In both cases it was found that pretreatment with PCP had no effect on the frequency of tumor induction, however liver lesions were found in the PCP treated mice. The LOAEL for this study, based on the 50 ppm dose group, was 5 mg/kg-day, assuming a daily food consumption of 10% of body weight.

Chronic Studies

Chronic studies in rodents are those with exposure periods of 90 days or greater. This section discusses noncarcinogenic effects of chronic exposure. Goldstein *et al.* (1977) investigated hepatotoxicity of technical and pure grade PCP in female Sherman rats administered PCP at doses of 0, 20, 100 and 500 ppm for eight months in the diet. Tech-PCP produced hepatic porphyria and increased hepatic aryl hydrocarbon hydroxylase activity, glucuronyl transferase activity, liver weight and cytochrome P₄₅₀ activity. Porphyria occurred at 100 and 500 ppm. In contrast pure PCP exhibited none of these effects at the doses tested, except that it did increase glucuronyl transferase activity at 500 ppm. The investigators concluded that tech-PCP produces a number of liver changes that cannot be attributed to PCP itself, but are consistent with the effects of chlorinated dioxins and furans.

Schwetz (1978) found some minor reproductive effects in rats treated with Dowicide EC-7 (90.4% pure). The impurities in this material are hexachlorobenzene, dioxins and furans. The NOAEL from this study was 3 mg/kg-day for reproductive effects and for chronic toxicity effects in female rats. The NOAEL for chronic toxicity in male rats was 10 mg/kg-day.

Carcinogenic Effects

This section evaluates the carcinogenicity data from animals and humans to determine which dataset would be most acceptable for calculation of upper-bound, individual excess lifetime cancer risks.

Animal Studies

The only animal study which is useful for determining a dose-response relationship and calculating a $q1^*$ is the NTP mouse study which is summarized in Tables 3 and 4. This study has been used by U.S. EPA and by the California Toxic Substances Control Program (now the Department of Toxic Substances Control (DTSC) to derive cancer potency values for human risk evaluation (California Department of Health Services, 1989). The difference between the two estimates was based on the use of different subsets of the data. U.S. EPA chose to combine data from all cancer types from both the tech-PCP and EC-7 experiments, but only for female mice, for reasons explained previously. DTSC chose to base its risk estimation on hepatocellular adenomas and carcinomas combined in male mice from the EC-7 experiment. Unlike U.S. EPA, DTSC used a body weight scaling factor without a power function to develop a human equivalent dose based on animal data.

U.S. EPA reviewed the NTP study and decided that it constitutes sufficient evidence for the carcinogenicity of PCP in animals, and that the data are suitable for human risk assessment. U.S. EPA conducted a risk assessment based on the geometric mean of the slope values for all tumor types produced in female mice by both tech-PCP and EC-7. The analysis was limited to female mice to place emphasis on the hemangiosarcomas which U.S. EPA determined were particularly relevant to potential human carcinogenicity, and because the male mice experienced significant early mortality in the bioassay. U.S. EPA used a scaling factor ($[70 \text{ kg}/0.03 \text{ kg}]^{1/3}=13.2$) based on surface area to adjust from animal to human cancer potency. As no data on pharmacokinetics were available, no adjustment for pharmacokinetic differences between the species was made.

DTSC also conducted a risk assessment based on the NTP bioassay. Unlike U.S. EPA, DTSC estimated the carcinogenic potency of PCP based on combined hepatocellular adenoma and carcinoma data from male mice exposed to EC-7 grade PCP. DTSC adjusted the data for early mortality by eliminating from the analysis animals that died too early to be at risk for developing tumors. This adjustment did not significantly affect the final result. In another difference from U.S. EPA, DTSC used a body weight scaling factor without a power function to derive the cancer potency estimate. DTSC used the $q1^*$ to directly calculate a Maximum Exposure Level (MEL).

OEHHA recommends that a scaling factor of 6.95 ($[70 \text{ kg}/0.03 \text{ kg}]^{0.25}$) be used to calculate a human equivalent cancer potency. This new methodology is based on U.S. EPA's 1996 proposed cancer risk assessment guidelines.

OEHHA proposes to base its risk assessment on hepatocellular adenoma and carcinoma data from male mice exposed to EC-7 because this data set represents the most significant positive trend. Data from tech-PCP are not considered applicable because a significant portion of its carcinogenicity may be due to impurities, particularly dioxins and furans. Data from female mice would yield cancer risk estimates which would be higher than those calculated from data for male mice (Table 3, final column). The data from the various tumor types produced in male mice (pheochromocytoma and malignant pheochromocytoma; or hepatocellular adenoma and carcinoma)

produce cancer potency estimates and PHGs which are substantially similar. Hepatocellular adenomas and carcinomas are fairly common in male B6C3F1 mice, whereas hemangiosarcomas and pheochromocytomas are not. The actual calculation of a PHG based on these data is explained below.

Human Studies

When adequate human data are available to estimate carcinogenic potency in humans, this is preferable to extrapolating from animal data. However, when human data are lacking or inadequate, it is prudent and generally accepted practice in risk assessment to use animal data to derive potential human cancer risk levels.

As described previously, there is some (but inadequate) epidemiological evidence to suggest that exposure to PCP is related to some human cancers. However, these studies are not conclusive that PCP is a human carcinogen, nor are they adequate to be used as the basis for a dose-response assessment. Therefore, it is appropriate to use animal data for estimating the carcinogenic potency of PCP to humans.

CALCULATION OF PHG

Noncarcinogenic Effects

A public health-protective drinking water concentration based on a noncarcinogenic health effects can be calculated by choosing the most appropriate animal study, and using the NOAEL from this study to calculate a safe exposure level for humans. For PCP, the animal study with the lowest NOAEL is the Knudsen (1974) subchronic (12 week) feeding study in Wistar rats in which the critical health effect was anemia. The NOAEL from this study was 1.21 mg/kg-day for the more sensitive male rats. Using this NOAEL one may calculate a health-protective drinking water concentration (C, in mg/L) using the following general equation:

$$C = \frac{\text{NOAEL} \times \text{BW} \times \text{RSC}}{\text{UF} \times \text{L/day}}$$

where,

NOAEL	=	No-observed-adverse-effect-level (use 1.21 mg/kg-day for PCP)
BW	=	Human body weight (a default of 70 kg for an adult)
RSC	=	Relative source contribution (use 80% or 0.8 for PCP)
UF	=	Uncertainty factors (a default of 10 for uncertainty in extrapolating from a subchronic study to chronic exposure, 10 for uncertainty in extrapolating from rats to humans, 10 for uncertainty in the variability of the human population)
L/day	=	Volume of water consumed daily by an adult (a default of 2 L/day).

Assuming most PCP exposure comes from drinking water, an RSC of 80% (0.8) is assumed. As a public health-protective estimate, OEHHA proposes an uncertainty factor of 1,000 for extrapolating from a subchronic animal study (rats) to humans and accounting for variability among humans (U.S. EPA, 1986).

Therefore,

$$\begin{aligned} C &= \frac{1.21 \text{ mg/kg-day} \times 70 \text{ kg} \times 0.8}{1,000 \times 2 \text{ L/day}} \\ &= 0.034 \text{ mg/L} = 34 \text{ ppb.} \end{aligned}$$

This method yields a health-protective drinking water concentration (C) of 0.034 mg/L (34 ppb).

Carcinogenic Effects

Linearized Multi-Stage Model

As discussed previously, the data set chosen for calculation of the cancer potency is the hepatocellular adenoma and carcinoma endpoint in male mice administered Dowicide EC-7 in the NTP bioassay (NTP, 1989). This data set represents the most significant positive trend, and results in a health-conservative estimate of cancer potency. The dose-response data from this experiment were entered in the GLOBAL 86 computer program (Howe *et al.*, 1986). The program calculated a $q1^*$ (animal) of $1.2 \times 10^{-2} \text{ (mg/kg-day)}^{-1}$, as indicated in Table 3. The $q1^*$ (human) was calculated from the $q1^*$ (animal) based on the formula:

$$q1^*(\text{human}) = q1^*(\text{animal}) \times [\text{BW}(\text{human})/\text{BW}(\text{animal})]^{1/4}$$

where,

$$\begin{aligned} \text{BW}(\text{human}) &= \text{the body weights of humans} \\ \text{BW}(\text{animal}) &= \text{the body weights of mice.} \end{aligned}$$

Therefore,

$$\begin{aligned} q1^*(\text{human}) &= 1.2 \times 10^{-2} \text{ (mg/kg-day)}^{-1} \times (70 \text{ kg} \div 0.03 \text{ kg})^{1/4} \\ &= 1.2 \times 10^{-2} \text{ (mg/kg-day)}^{-1} \times 6.95 \\ &= 8.34 \times 10^{-2} \text{ (mg/kg-day)}^{-1} \end{aligned}$$

Based on this $q1^*$ (human), public health-protective concentrations (C) based on the carcinogenic endpoint can be calculated using the general equation:

$$C = \frac{\text{BW} \times R}{q1^* \times \text{L/day}}$$

where,

$$\begin{aligned} \text{BW} &= \text{Body weight for an adult male (70 kg)} \\ R &= \text{The } de \text{ minimis } \text{theoretical lifetime excess individual cancer risk level of } 10^{-6} \\ \text{L/day} &= \text{Volume of water consumed daily by an adult (a default of 2 L/day).} \end{aligned}$$

Therefore,

$$\begin{aligned} C &= \frac{70 \text{ kg} \times 1 \times 10^{-6}}{[8.34 \times 10^{-2} (\text{mg/kg-day})^{-1}] \times 2 \text{ L/day}} \\ &= 4.2 \times 10^{-4} \text{ mg/L} = 0.42 \text{ ppb.} \end{aligned}$$

A public health-protective concentration for PCP based on carcinogenicity using the $q1^*$ is 0.42 ppb.

LED₁₀ Model

Alternatively, a public health-protective concentration for PCP can be calculated, as recommended by the U.S. EPA's 1996 proposed guidelines for carcinogen risk assessment (U.S. EPA, 1996), from the cancer slope factor (CSF) and the general equation for calculating a public health-protective concentration (C) for carcinogenic endpoints:

$$C = \frac{BW \times R}{CSF \times L/\text{day}}$$

where,

BW	=	Body weight for an adult male (70 kg)
R	=	The <i>de minimis</i> theoretical lifetime excess individual cancer risk level of 10^{-6}
CSF	=	$0.1/\text{LED}_{10}$, where the LED_{10} is the lower-bound on dose corresponding to the 95% confidence limit, calculated by GLOBAL 86 or similar programs
L/day	=	Volume of water consumed daily by an adult (a default of 2 L/day).

Therefore,

$$\begin{aligned} C &= \frac{70 \text{ kg} \times 1 \times 10^{-6}}{[8.11 \times 10^{-2} (\text{mg/kg-day})^{-1}] \times 2 \text{ L/day}} \\ &= 4.3 \times 10^{-4} \text{ mg/L} = 0.43 \text{ ppb} \end{aligned}$$

A public health-protective concentration for PCP based on carcinogenicity using the LED_{10} is 0.43 ppb.

Using either the linearized multistage model or the LED_{10} model, the upper-bound individual excess lifetime cancer risk estimates for public health-protective concentrations are comparable. Furthermore, the public health-protective concentration of 34 ppb that was calculated based on noncarcinogenic health effects is significantly greater than the values calculated based on carcinogenicity.

Therefore, OEHHA calculates a PHG of 4×10^{-4} mg/L (0.4 ppb) for PCP in drinking water.

RISK CHARACTERIZATION

The PHG of 0.4 ppb is lower than the current U.S. EPA MCL of 1 ppb which was adopted in 1991 (U.S. EPA, 1991). The U.S. EPA MCL is based on a different subset (female instead of male mice) of the same carcinogenicity data on which the PHG is based, and a different scaling factor for the body weights. These federal standards are much lower than the U.S. EPA drinking water health advisories, which are 1 mg/L for one day, or 0.3 mg/L for 10 days, based on noncarcinogenic liver effects in animals. These are different because the exposure durations and endpoints are different. For risk management purposes, public health-protective concentrations of 4.3 and 43 ppb can be calculated assuming theoretical excess individual lifetime cancer risk levels of 10^{-5} and 10^{-4} , respectively.

There are several significant sources of uncertainty in determining potential human health risks for PCP in drinking water. The best available data come from animal studies. Extrapolating from animals to humans is always an uncertain process. For example, OEHHA is currently using a scaling factor of body weight ratio to the 1/4 power to extrapolate carcinogenic potency from animal to human. In the past OEHHA used body weight ratio to the 1/3 power to make this extrapolation. This results in an almost two-fold decrease in potency estimates when mice are used.

There is uncertainty owing to the impurities in the test materials. It is not certain whether the carcinogenicity is due to PCP, to the impurities, or to the combined action of both.

Another source of uncertainty is the choice of tumor data sets on which to base the PHG. Concentrations corresponding to upper bound cancer risk levels based on various tumor data sets are shown in Table 3. Of these, OEHHA used the data set of hepatocellular adenomas and carcinomas in male mice dosed with Dowicide EC-7. This data set yielded the most significant positive trend in statistical analysis. Other risk assessors, including U.S. EPA, have chosen to use other data sets.

For PHGs, our use of the relative source contribution (RSC) has, with a few exceptions, followed U.S. EPA drinking water risk assessment methodology. U.S. EPA has treated carcinogens differently from noncarcinogens with respect to the use of RSCs. For noncarcinogens, RfDs (in mg/kg-day), drinking water equivalent levels (DWELs, in mg/L) and MCLGs (in mg/L) are calculated using UFs, body weights and water consumption rates (L/day) and the RSC, respectively. The RSC range is 20% to 80% (0.2 to 0.8) depending on the relative sources.

U.S. EPA follows a general procedure in promulgating MCLGs:

1. if Group A and B carcinogens (i.e., strong evidence of carcinogenicity) MCLGs are set to zero,
2. if Group C (i.e., limited evidence of carcinogenicity), either an RfD approach is used (as with a noncarcinogen) but an additional UF of 1 to 10 (usually 10) is applied to account for the limited evidence of carcinogenicity, or a quantitative method (potency and low-dose extrapolation) is used and the MCLG is set in the 10^{-5} to 10^{-6} cancer risk range
3. if Group D (i.e., inadequate or no animal evidence) an RfD approach is used to promulgate the MCLG.

For approaches that use low-dose extrapolation based on quantitative risk assessment, U.S. EPA does not factor in an RSC. The use of low-dose extrapolation is considered by U.S. EPA to be adequately health-protective without the additional source contributions. In developing PHGs, OEHHHA has adopted the assumption that RSCs should not be factored in for carcinogens grouped in U.S. EPA categories A and B and for C carcinogens for which a cancer potency has been calculated based on low-dose extrapolation. This is an area of uncertainty and scientific debate and it is not clear how this assumption impacts the overall health risk assessment.

There are other sources of uncertainty such as differences in body weight and water consumption in the general population. These sources of uncertainty are common to all drinking water chemical contaminant risk assessments.

OTHER STANDARDS

U.S. EPA has set an MCLG of zero and an MCL of 1 ppb based on carcinogenicity in animals (U.S. EPA, 1991). The California MCL for PCP is 1 ppb. U.S. EPA has also established drinking water health advisories of 1.0 mg/L for one day, or 0.3 mg/L for 10 days based on noncarcinogenic liver effects in animals. A RfD of 0.03 mg/kg-day for PCP was developed by U.S. EPA based on a rat oral chronic study (Schwetz *et al.*, 1978) with kidney and liver pathology being the critical effects (U.S. EPA, 1997).

Both the threshold limit value (TLV) and the permissible exposure limit (PEL), established by the American Conference of Government and Industrial Hygienists (ACGIH) and the Occupational Safety and Health Administration (OSHA) respectively, are set at 500 mg/m³. Both of these assume inhalation as the route of exposure.

Other states have drinking water quality guidelines ranging from 6 ppb (Maine) to 220 ppb (Kansas and Montana). New York State has a drinking water quality criterion of 21 ppb (ATSDR, 1994).

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